炭素のケミカルスパッタリングIV（堆積炭素）

松波 紀明　名大、エコトピア科学研究所
仲野 友英、久保 博孝、左高 正雄　原子力研究開発機構
大野 哲靖　名大、工学研究科
山際 正人、寺岡 正広　名大、工学研究科

Contents

1. Introduction: Background, 2007-2009 Reports & Aim
2. 堆積炭素とは; Redeposit C, CFC (Carbon nanotube?), Aim & Literature survey
3. Temp., Energy & Fluence dependences, Dopant effect
4. Summary, Graphite vs W
5. Dynamic retention

Background: Graphite for fusion-plasma walls

H(D) on pure-graphite [2007 Report]

- **Chemical sputtering**: Reaction of H(D) with C, formation and escape of hydrocarbons.

* For H energy > 0.3 keV, yield takes maximum at Ts~800K, CH_4 dominant, larger by an order of magnitude than physical sputtering

  e.g. ~0.01 /ion for 1 keV H ,Matsunami et al. ADNDT 31(1984)1., Yamamura et al. ADNDT62(1996)149.

- For low energy, Ts~600K, contribution other than CH_4 becomes larger.

* c.f. Enhanced sublimation, >1200K, Philips et al. JNM 155-157(1988)319.

*NB. Reflection, ~0.1 at 1 keV H on C, Tabata et al. NIM B9(1985)113

*Related phenomena: Reemission, Retention

H(D) on doped-graphite [2008 Report]

Dopant (10 elements)

B, Be, Si, Ti, W, V, Fe, Cr, Li, Zr

Suppression of chemical sputtering.

~10 % doping is effective.

O & N impact on graphite [2009 Report]

Chemical sputtering

O impact, CO (main component), Yield ~1

Energy Distribution of CO at RT, MB + Collision cascade

N impact, Yield ~1

(C impact, chemical sputtering was not observed.)

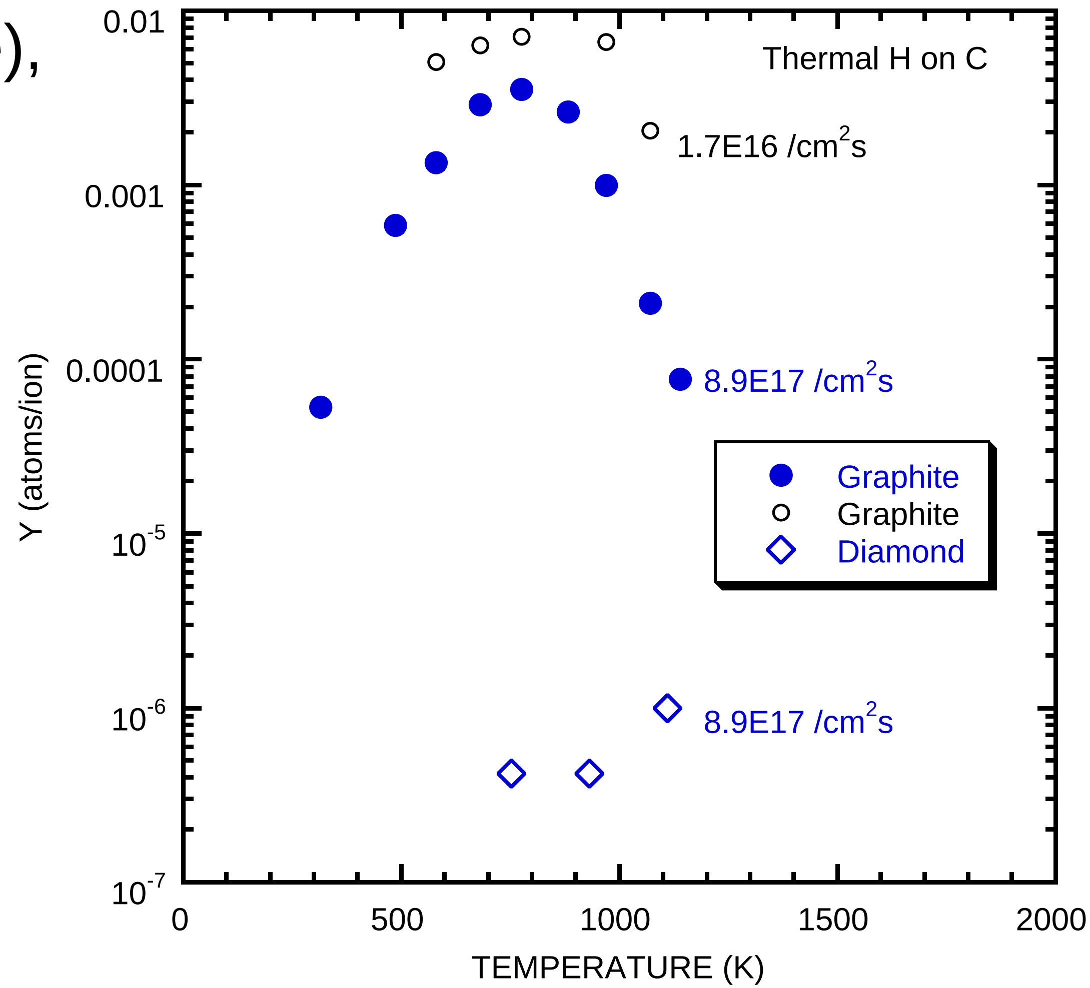
Graphite vs Diamond

DGM1997a 2k7.2.15

C.D.Donnelly, R.W.McCullough, J. Geddes, Diamond & Related Mat. 6(1997)787.

Y(diamond) << Y(graphite),
> 3 order of magnitude

Desired are the data for energetic H impact.



Thermal H on a:C(H), Horn et al. Chem. Phys. Lett. 231(1994)193.
*CH_3 emission max. at 600 K
Y ~ 0.01
Inconsistent

C. M. Donnelly, R.W. McCullough, J. Geddes, Diamond Rel. Mat. 6(1997)787.

堆積炭素のケミカルスパッタリング [2010 Report]

***堆積炭素とは？** Re-deposited C

Wide variation of
SP2+SP3, Structure, Density, Impurities

***Lab. Exp.**
Carbon fiber-reinforced carbon composite (CFC)

***Similarity to Carbon nanotube?**

Aim

*** Data compilation & understanding of chemical sputtering of graphite: CFC**

* **CFC: ~14 papers [2010 Report]**

Temperature Dependence(1)

0.6 keV H_2 on DC & Graphite

*Chemical sputtering Yields
DC < Graphite

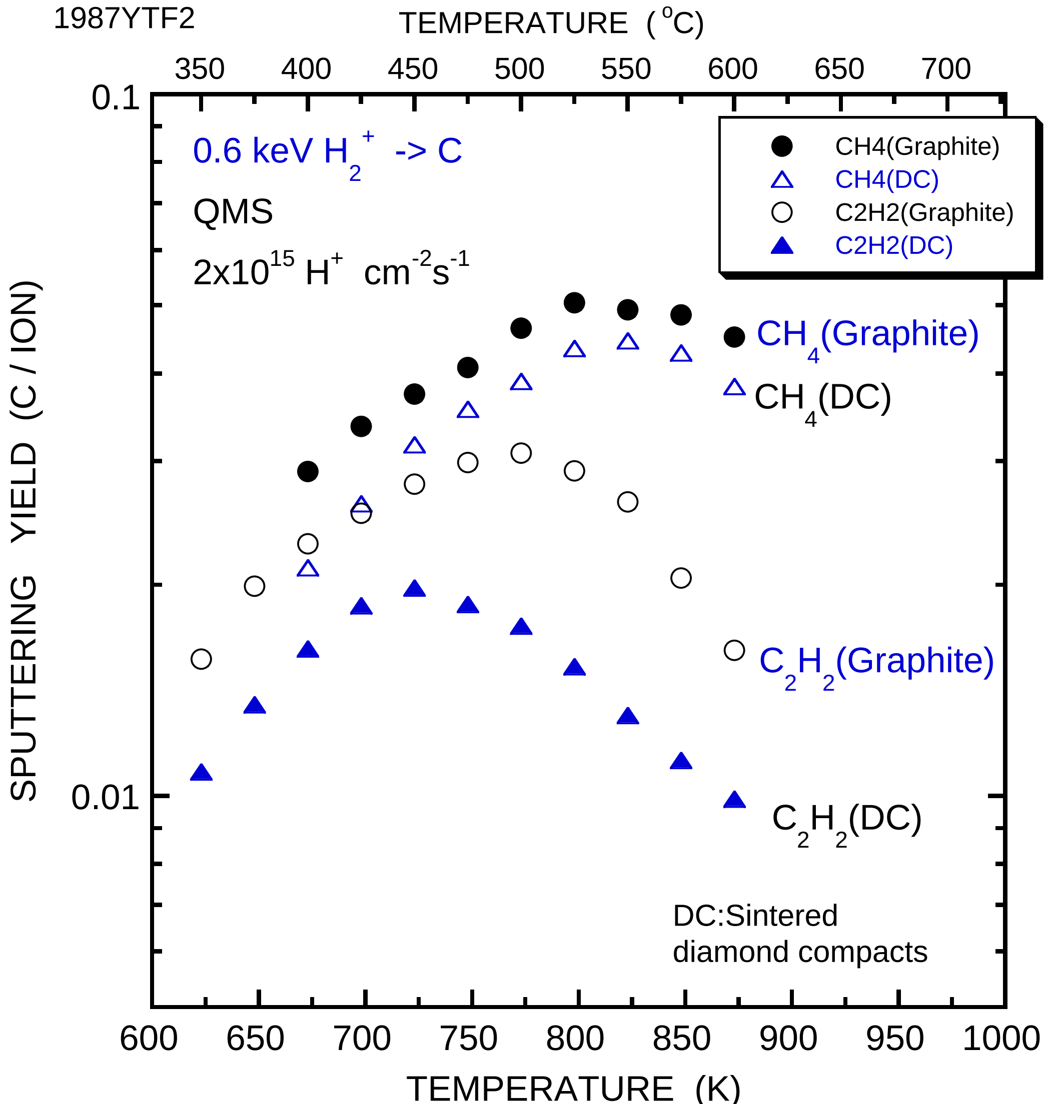
*DC, density~2.2 gcm^{-3}
diamond 2.26 gcm^{-3}

***SP3 is remained after ion impact (Raman spectroscopy)**

Ion Impact Graphitization ?

SP2/SP3 before and after ion impact?

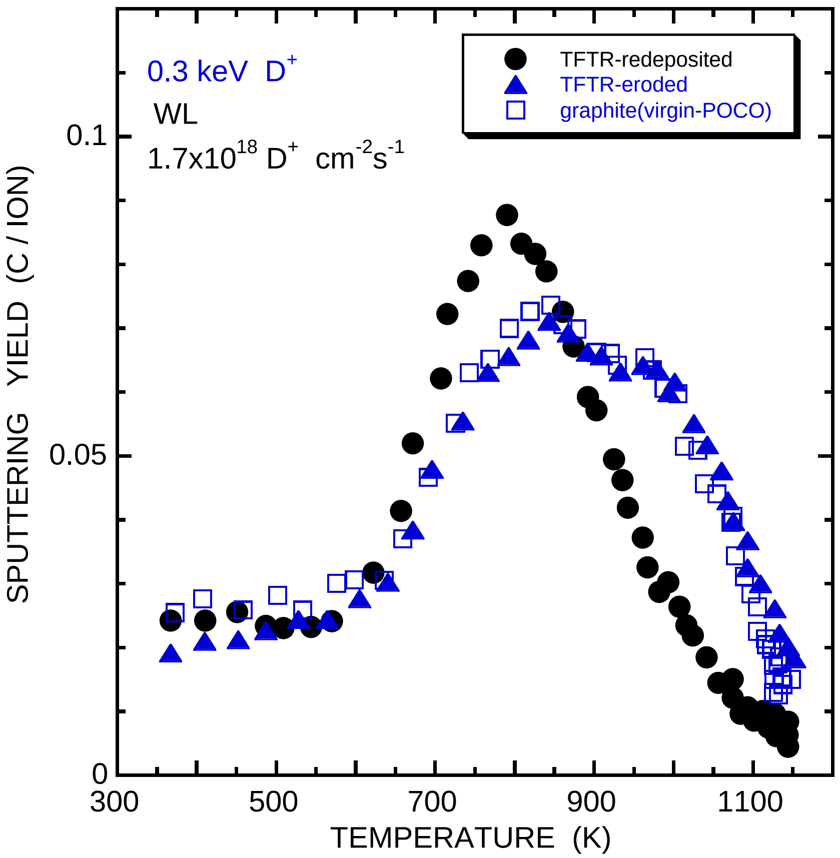
Phys. Sputtering ~0.01 (0.3 keV H)



R. Yamada, J. Vac. Sci. Technol. A5(1987)2222.

Temperature Dependence(2)

1989HPCTF5



Y. Hirooka, A. Pospieszczyk, R. W. Conn, B. Mills, R. E. Nygren, Y. Ra, J. Vac. Sci. Technol. A7(1989)1070.

TFTR-redeposit C

***Chem. Sp. Yield is larger by ~20 % than Graphite**

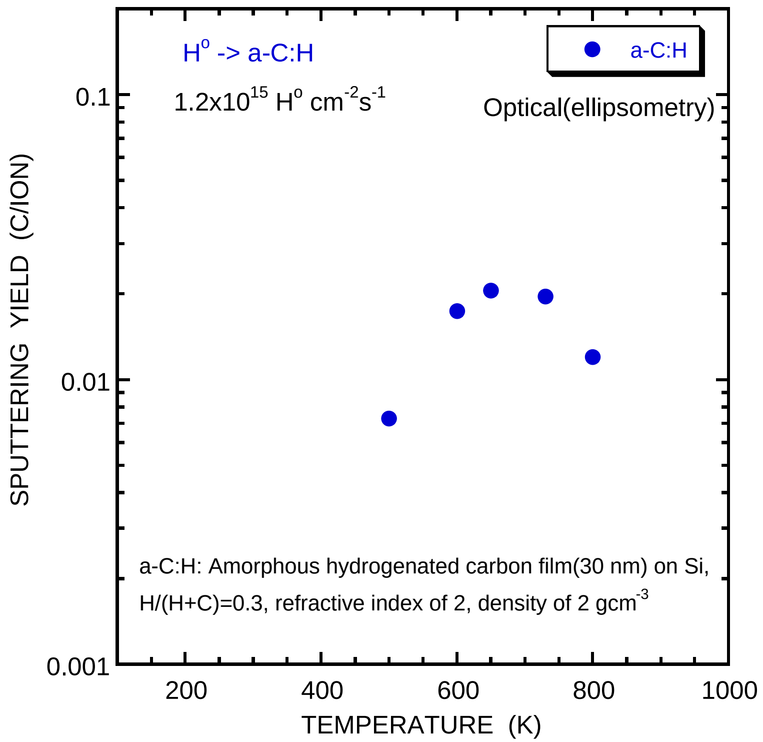
*** Impurity (O, Si, S, Cr, Fe, Ni) inclusion**

Phys. Sp. Y. ~ 0.01

Normal incidence.

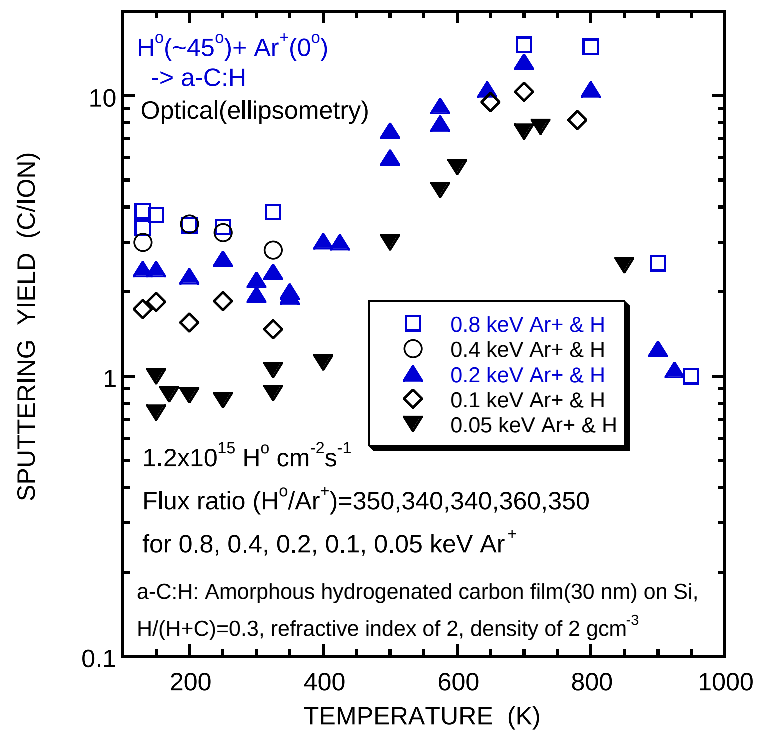
Temperature Dependence(3)

2008SHSTF2



M. Schluter, C. Hopf, T. S.-Selinger, W. Jacob,
J. Nucl. Mater. 376(2008)33.

2008SHSTF3



M. Schluter, C. Hopf, T. S.-Selinger, W. Jacob,
J. Nucl. Mater. 376(2008)33.

Cf. Diamond

Y(a-C:H) >> Y (Diamond)

$\sim 10^{-5}$

Ar+ & H impact

Synergistic effect

Y(phys. sp.) ~5 (0.8 keV Ar)

Energy Dependence(1a)

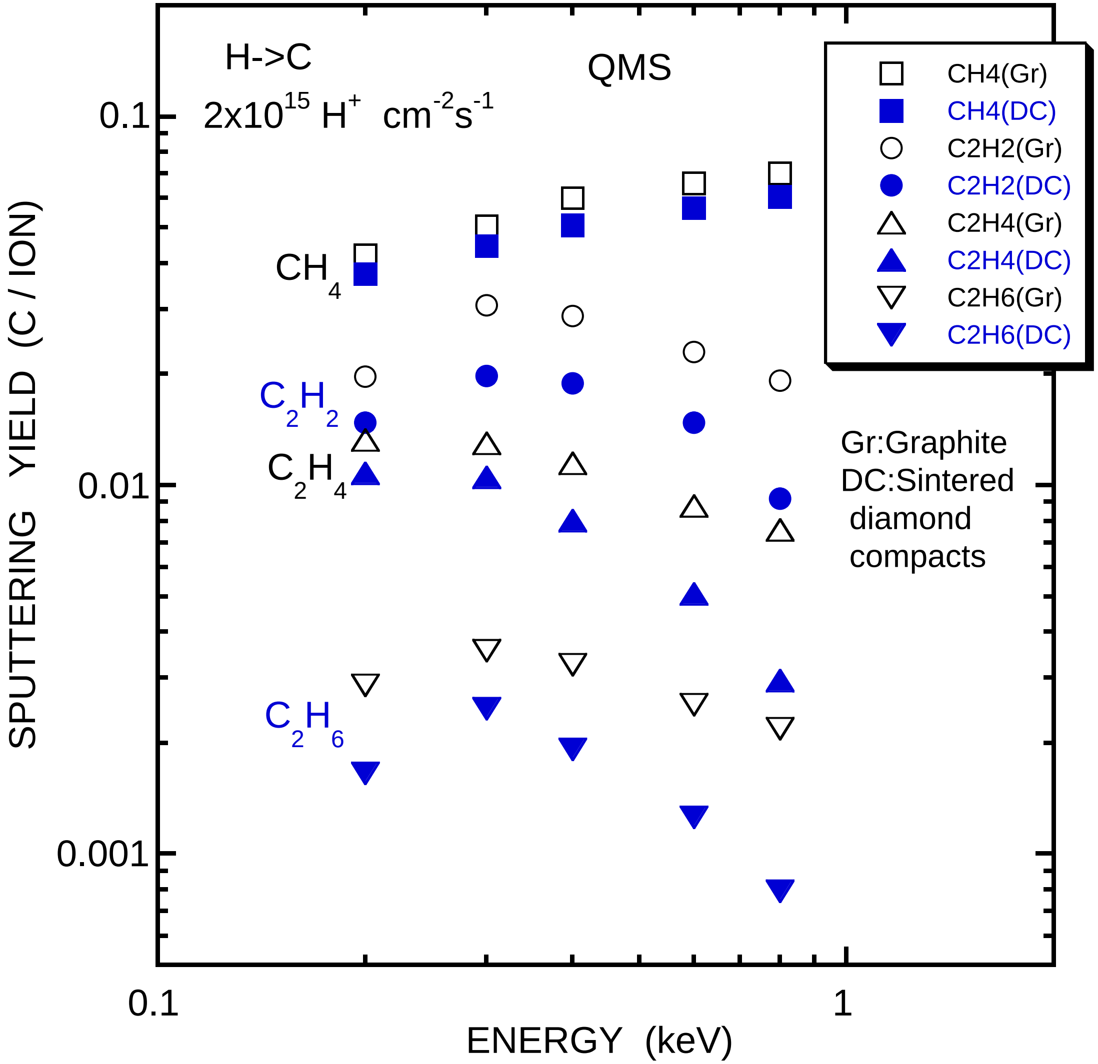
***Chem. Sp.**

***CH Component**

1. DC ~ Graphite

2. $C_1(CH_4)$ > $C_2(C_2H_2$ etc)

1987YEF3



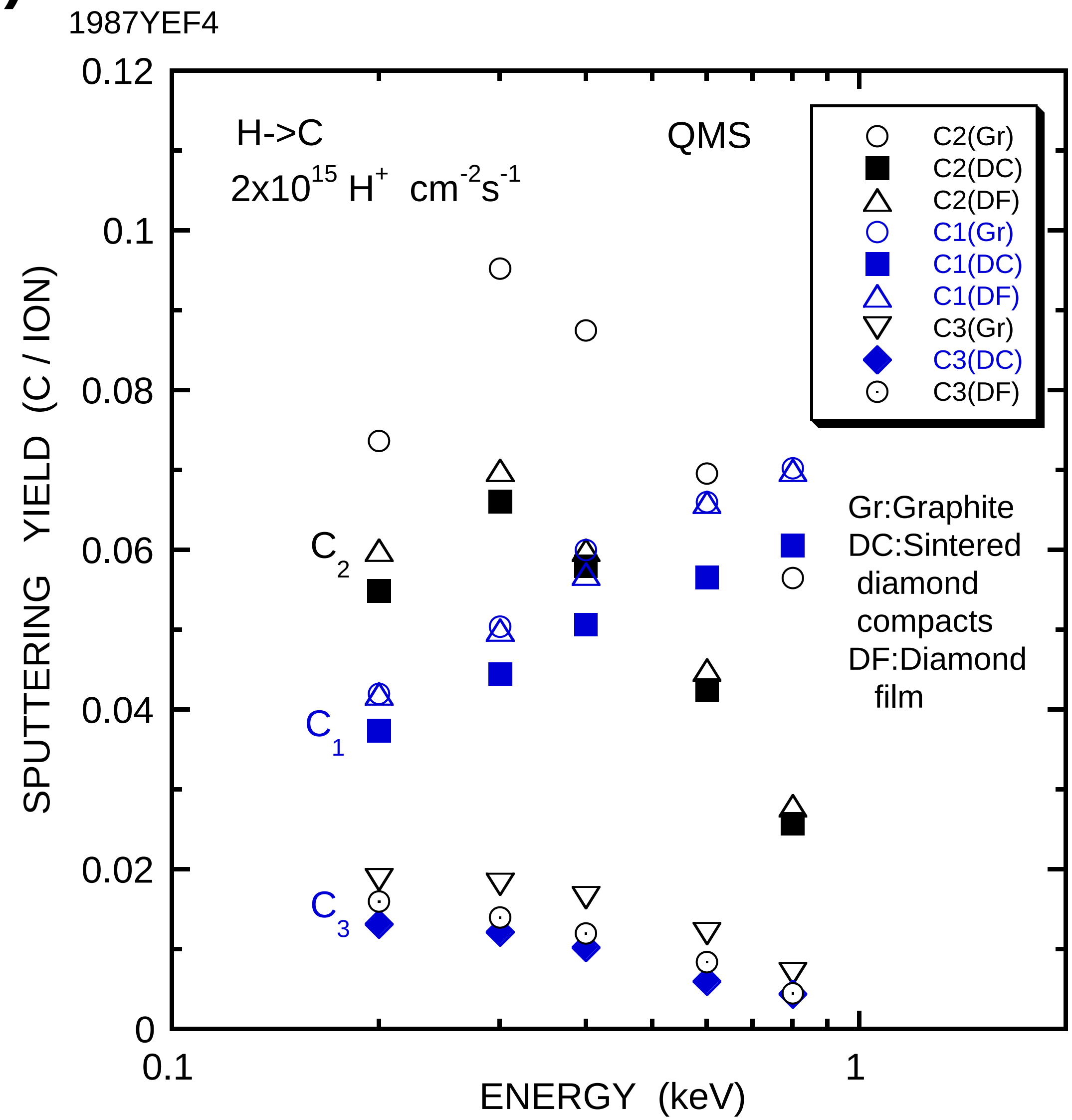
R. Yamada, J. Vac. Sci. Technol. A5(1987)2222.

Energy Dependence(1b)

*Chem. Sp. ≥ Phys. Sp.

*E < 1 keV

1. C_2(C_2H_2 etc),
   DC & DF < Graphite
2. C_1(CH_4), C_3(C_3H_8),
   DC~DF~Graphite



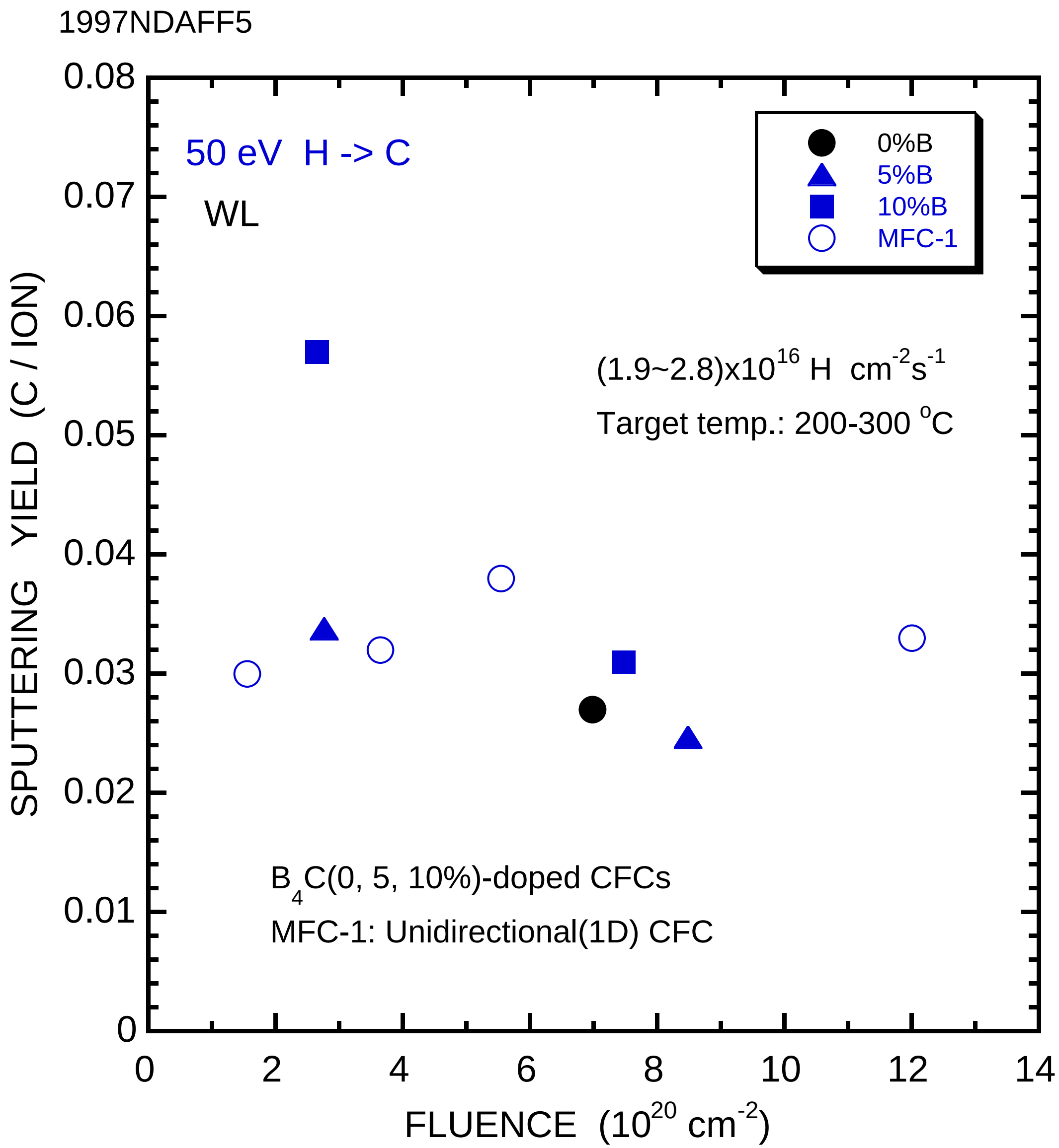
R. Yamada, J. Vac. Sci. Technol. A5(1987)2222.

Fluence Dependence

***Fluence Dep. ~ Weak**

***B-doping: Little effect**

***Data at higher temp. is desired.**

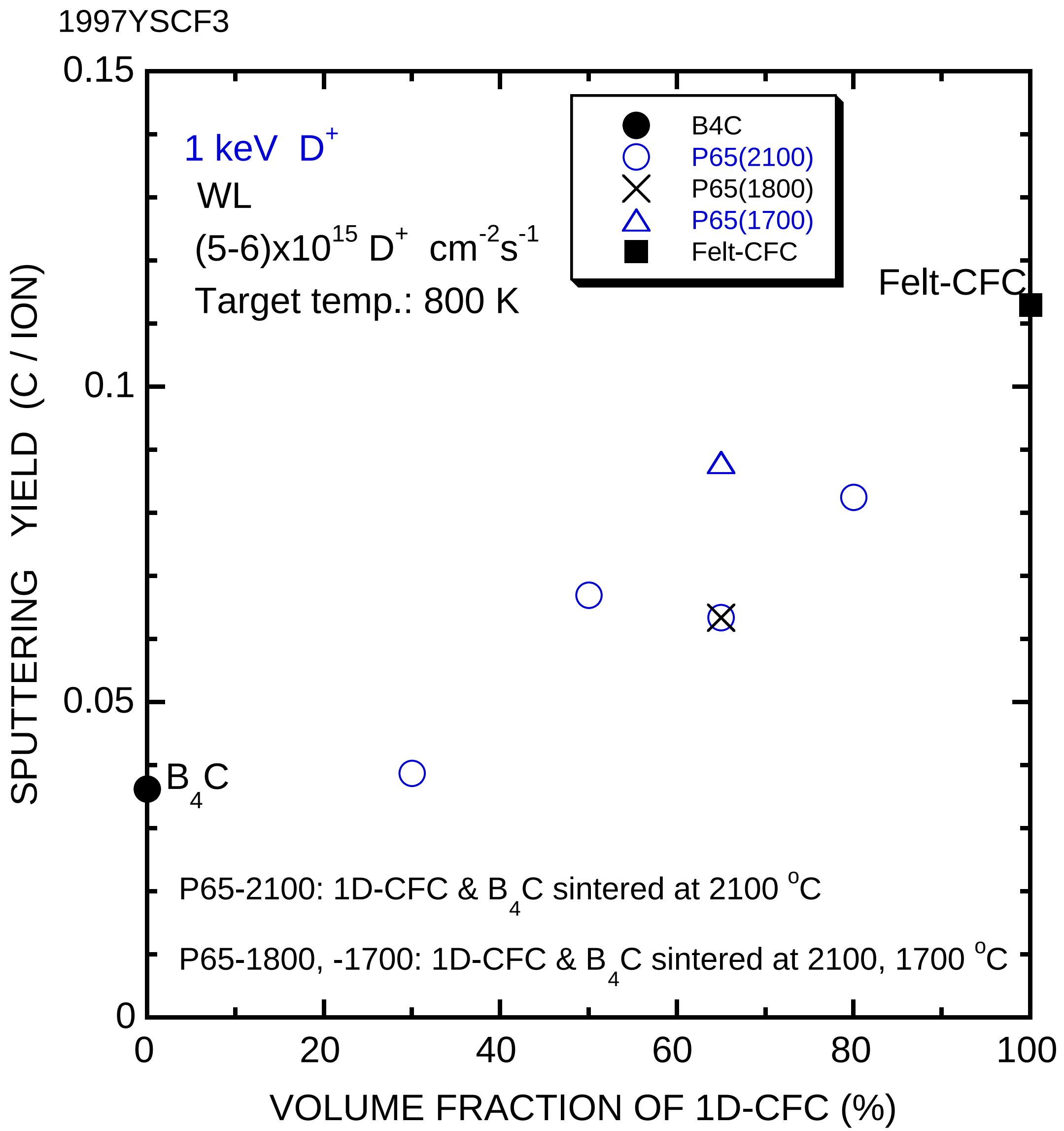


K. Nakamura, M. Dairaku, M. Akiba, Y. Okumura, J. Nucl. Mater. 241-243(1997)1142.

Dopant Effect

B-doping

Suppression of Chem. Sp.



T. Yamaki, Y. Suzuki, A. Chiba, M. Nakagawa, Y. Gotoh, R. Jimbou, M. Saidoh,J. Nucl. Mater. 241-243(1997)1132.

Summary

- **Survey of chemical sputtering data: CFC**
- **Appreciable chemical sputtering, Comparable with Graphite**

  Ion induced graphitization?, Comparison with Diamond?

Future problems

- **Graphite vs W**

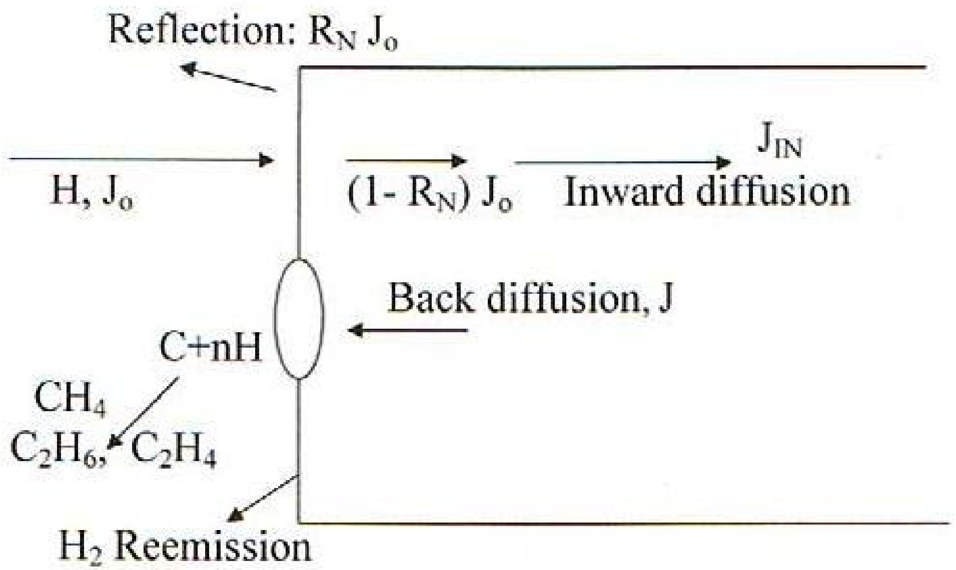
  Comparison; Mechanical, Thermal, etc. Properties

  Gr.; Suppression of Chemical sputtering

  H Retention (static, dynamic)
- **A simple analytical formula?**
- **Data compilation, publication?**

Model: pure graphite

S.K.Erents, C.M.Braganza, G.M.McCracken, J. Nucl. Mat.63(1976)399.



H, O, N impact

Hydrocarbon

CO, CO_2, C_2N_2

$Y_{chem}=n_H$*cnst*exp($-Q_1/RT$),

n_H:H conc. at surfce, $dn_H/dt = J - J_o \sigma n_H - n_H/(\tau_0 \exp(Q_2/RT))$

ion-induced desorption thermal desorption

Q_1: 159kJ/mol, activation energy (heat of CH_4 formation?)

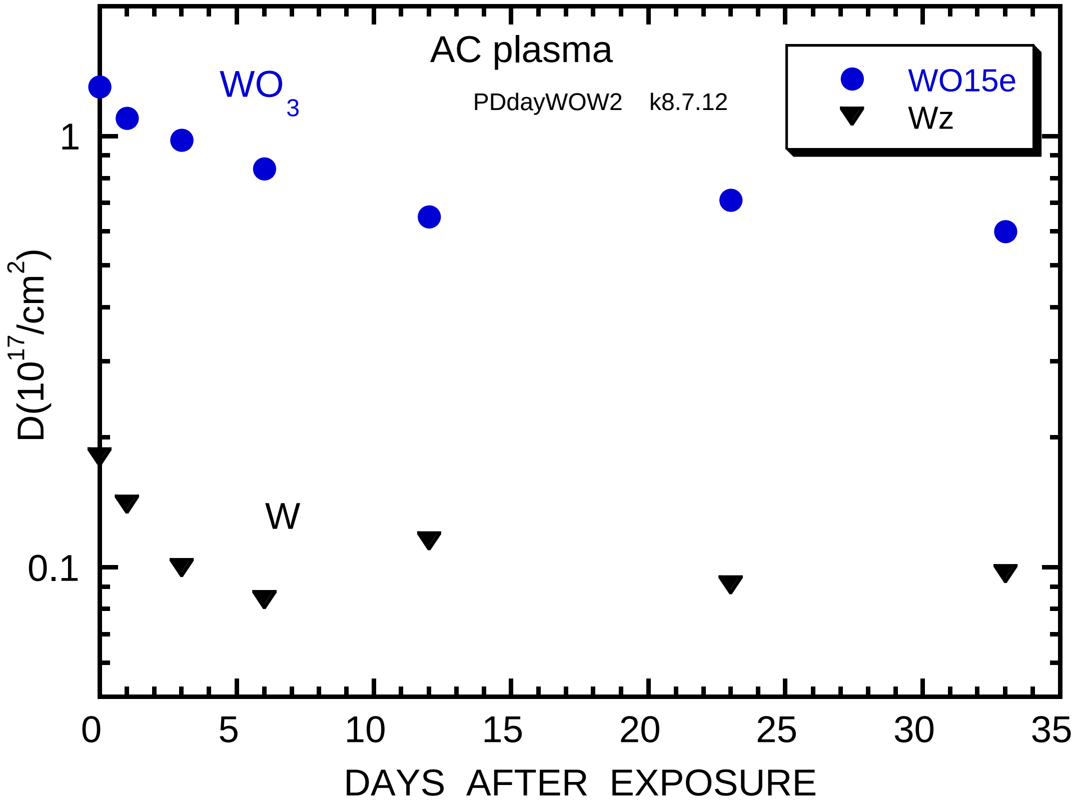
Q_2: 228kJ/mol

R_N: Reflection coefficient

Deuterium Retention in WO_3 and W

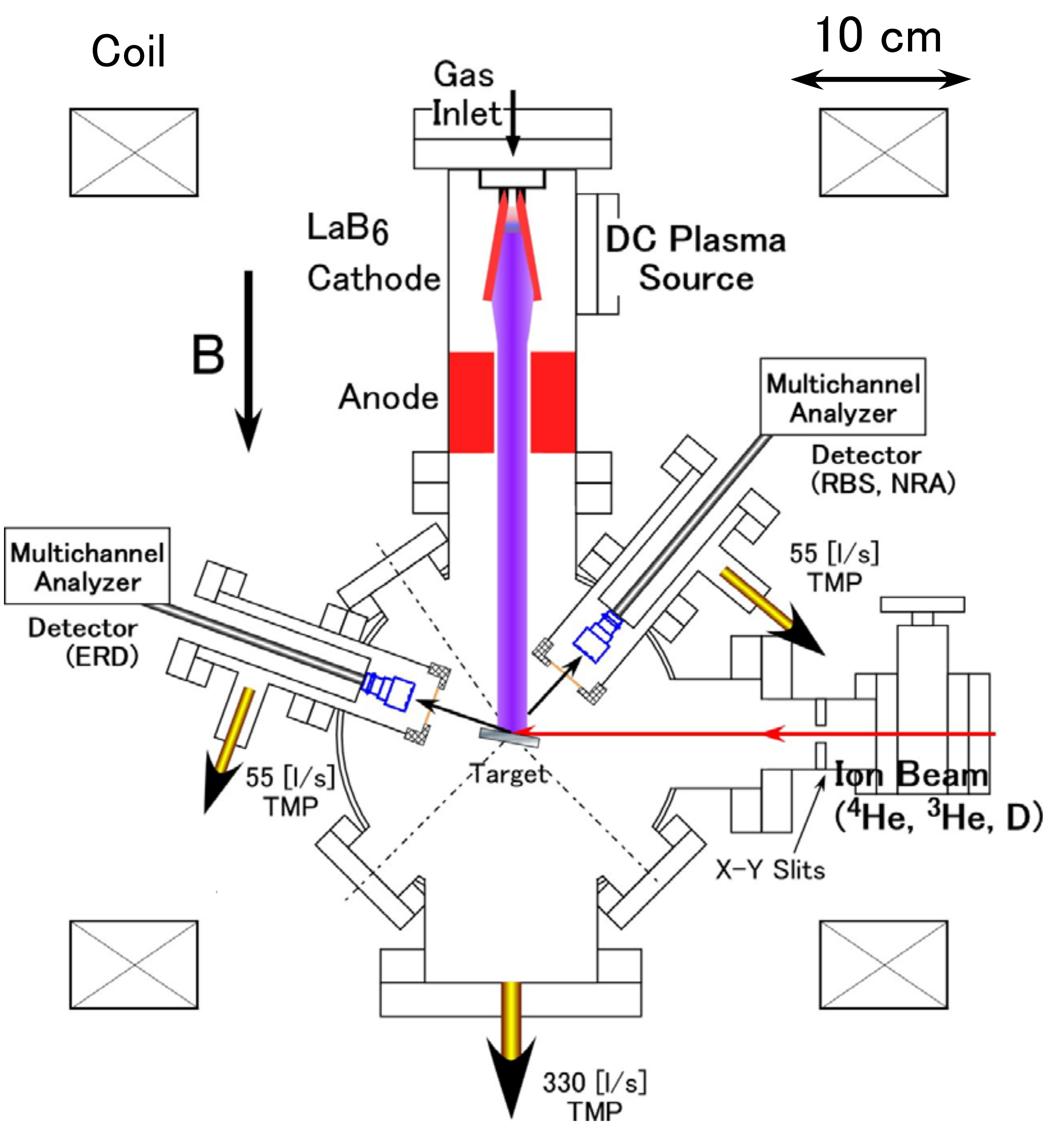
When WO_3(D) & W(D) are kept in air at RT, Deuterium Escape was observed.

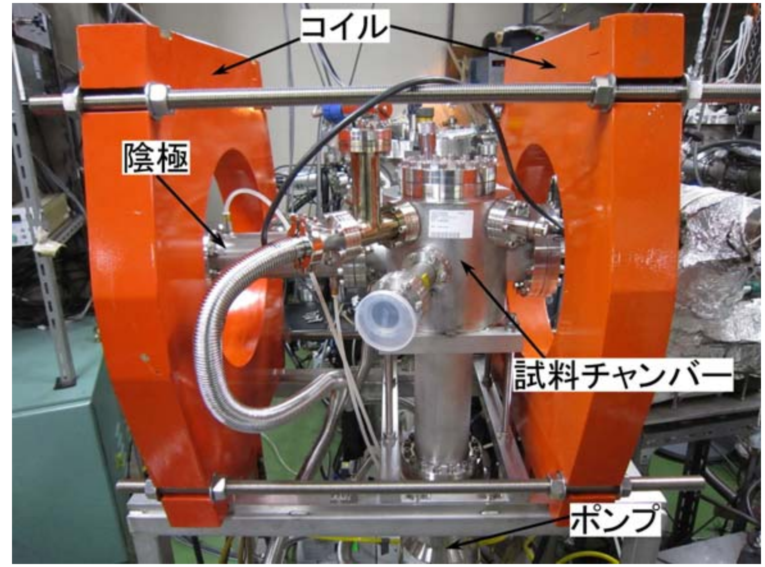
***Dynamic Retention**



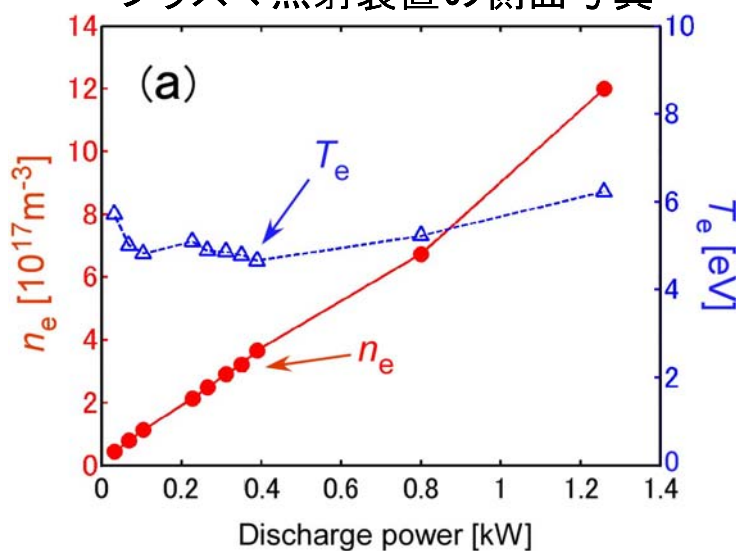
1.5 kV AC (60 Hz), Maximum D energy= 1.06 keV, Efficiency ~4%, Reflection ~50%(D on W),
*Dynamic Retention

開発した小型高熱流プラズマ照射装置





プラズマ照射装置の側面写真



プラズマ特性図(投入電力依存性)